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Upscaling Carbon Fluxes over Great Plains Grasslands: Sources and Sinks

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1. Introduction

Grasslands constitute the major land cover (61%) in the U. S. Great Plains (NLCD 2001) with the C_3 grassland dominant in the north and C_4 species prevalent in the south. Our previous study on the Northern Great Plains grasslands found net ecosystem exchange (NEE, ecological sign convention, opposite of atmospheric science, to show efflux of CO_2 as negative and uptake of CO_2 from the atmosphere as positive) was highly variable during 2000 and 2006 affected by droughts (Zhang et al., 2010). In this study, we extended our study from the Northern Great Plains (Wylie et al., 2007; Zhang et al., 2007; Zhang et al., 2010) to the entire Great Plains grasslands (Figure 1) using 34 site-years of CO_2 exchange measurements at 15 flux towers. We developed a rule-based piecewise regression (PWR) model to map NEE at 7-day intervals and 250-m spatial resolution. We aimed to 1) develop satellite remote sensing models for estimating NEE with MODIS data and flux tower measurements, 2) quantify the interannual variability of NEE for 2000 to 2008, and 3) identify the carbon sink and source activities in different regions.

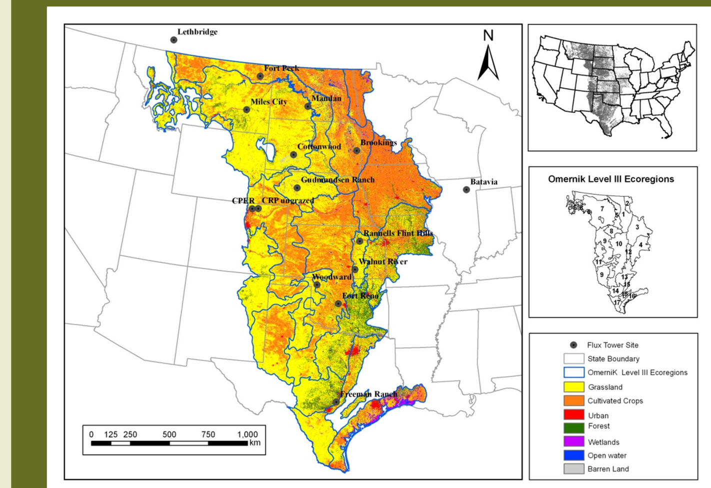

Figure 1. Study area and grassland flux towers in the Great Plains.

In the Omernik Level III Ecoregion map on the right-central panel, the number represents: 1 Northern Glaciated Plains, 2 Lake Agassiz Plain, 3 Western Corn Belt Plains, 4 Central Irregular Plains, 5 Northwestern Glaciated Plains, 6 Montana Valley and Foothill, 7 Northwestern Great Plains, 8 Nebraska Sandhills, 9 Western High Plains, 10 Central Great Plains, 11 Southwestern Tablelands, 12 Flint Hills, 13 Central Oklahoma/Texas Plains, 14 Edwards Plateau, 15 Texas Blackland Prairies, 16 Western Gulf Coastal Plain, 17 Southern Texas Plains.

2. Model Method

The PWR model integrates spatial data sets and 15 flux tower data sets to estimate the spatio-temporal carbon fluxes. The gap-filled NEE data for these sites (originally from AmeriFlux and AgriFlux networks) were taken from the WorldGrassAgriflux database (Gilmanov et al. 2010). The more important predictive variables for the final PWR model included the 7-day composites from 250-m eMODIS normalized difference vegetation index (NDVI), phenological metrics, three climatic variables (precipitation, temperature, photosynthetically active radiation), and soil water holding capacity (WHC). We took 12 selected variables to train the final PWR model for mapping NEE in the Great Plains.

3. Results

3.1 Model Accuracy Assessment

We compared the PWR-estimated NEE with the tower-measured NEE using leave-one-out cross-validation (LOOCV) by withholding each site and each year. The comparisons of tower-measured and PWR-estimated NEE in the LOOCV indicated $r = 0.61 – 0.98$ for NEE estimation by withholding sites, and $r = 0.81 – 0.92$ for withholding years. After assessing the model performance with the LOOCV method, we trained the final model using the complete flux tower data set. The final PWR model accuracy was reasonably high with $r = 0.88$. We compared the PWR-estimated NEE with the tower-measured NEE for each site in the 7-day interval (Figure 2), which showed that our estimated NEE captured most of seasonal NEE variations.

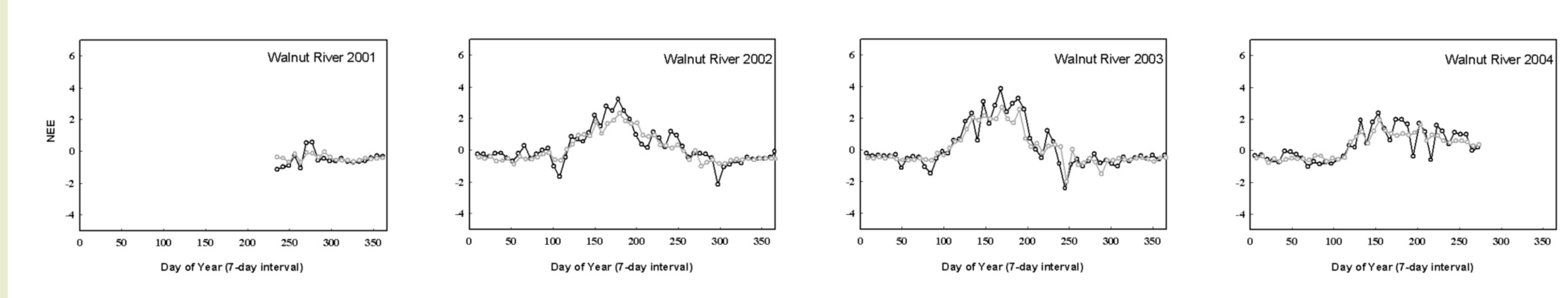

Figure 2. The agreement of seasonal dynamics of measured and estimated NEE ($g\ C \cdot m^{-2} \cdot day^{-1}$) at the 15 flux towers at 7-day interval. The black line represents the measured NEE. The gray line represents the estimated NEE.

3.2 Source/Sink Activity of the Great Plains grasslands

The annual NEE ranged from 0.3 $g\ C \cdot m^{-2} \cdot yr^{-1}$ in 2002 to 47.7 $g\ C \cdot m^{-2} \cdot yr^{-1}$ in 2005 over the Great Plains grasslands for the years 2000–2008 (Figure 3). During our study period, the average annual NEE was 24 ± 14 $g\ C \cdot m^{-2} \cdot yr^{-1}$ and the cumulative flux was 214 $g\ C \cdot m^{-2}$. The Great Plains grassland was a carbon sink with the total of 2,996 Tg C during 2000–2008.

In the Great Plains grasslands, areas of carbon sinks (from 0 to 150 $g\ C \cdot m^{-2} \cdot yr^{-1}$) were noticeably larger in 2005 and 2001 (Figure 4). Most of the areas in 2005 were carbon sinks with about 100 $g\ C \cdot m^{-2} \cdot yr^{-1}$. At the other extreme, most of the areas in 2002 and 2006 were carbon sources with about–150 $g\ C \cdot m^{-2} \cdot yr^{-1}$.

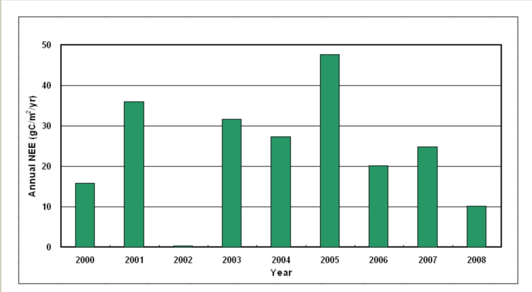

Figure 3. The annual NEE over the Great Plains grasslands for years 2000–2008.

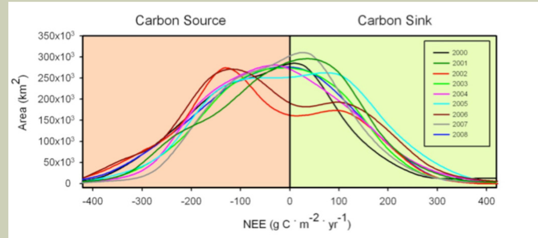

Figure 4. Areal distribution of annual NEE in the Great Plains grasslands during 2000–2008.

Figure 5 illustrates the spatial distribution of annual NEE above the Great Plains grasslands. Considerable spatial heterogeneity was observed with extensive carbon sources in the western regions (especially in the southwest) and carbon sinks in the eastern regions. For the years 2002, 2004, and 2006, extensive carbon sources occurred in the Northwestern Great Plains.

Figure 6 illustrates the spatial distribution of seasonal NEE above the Great Plains grasslands for 2002 (smallest carbon sink) and 2005 (largest carbon sink). Spring and summer are the two main seasons that contribute to carbon sink. The seasonal NEE had different spatial distributions in 2002 and 2005. In summer, NEE is dominated by negative values (sources) in the west but positive values (sinks) in the east. However, comparing to 3005, the year 2002 had more extensive and intensive carbon sources in the west of the Great Plains, especially in the Northwestern Great Plains.

Temporally, the Great Plains grassland were carbon sinks from April to the end of July and then gradually changed to carbon sources (Figure 7). The trajectory of the mean 7-day NEE for each year over the entire Great Plains grassland showed the year 2002 has the lowest NEE values and the year 2005 has the highest NEE in magnitudes.

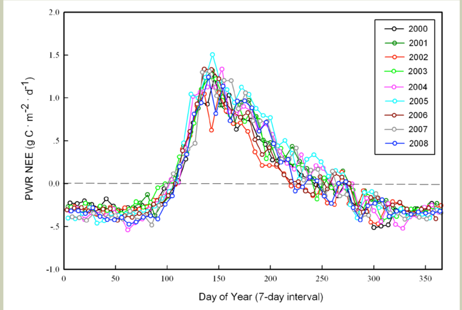

Figure 7. Predicted mean 7-day NEE for the Great Plains grasslands for each year during 2000-2008.

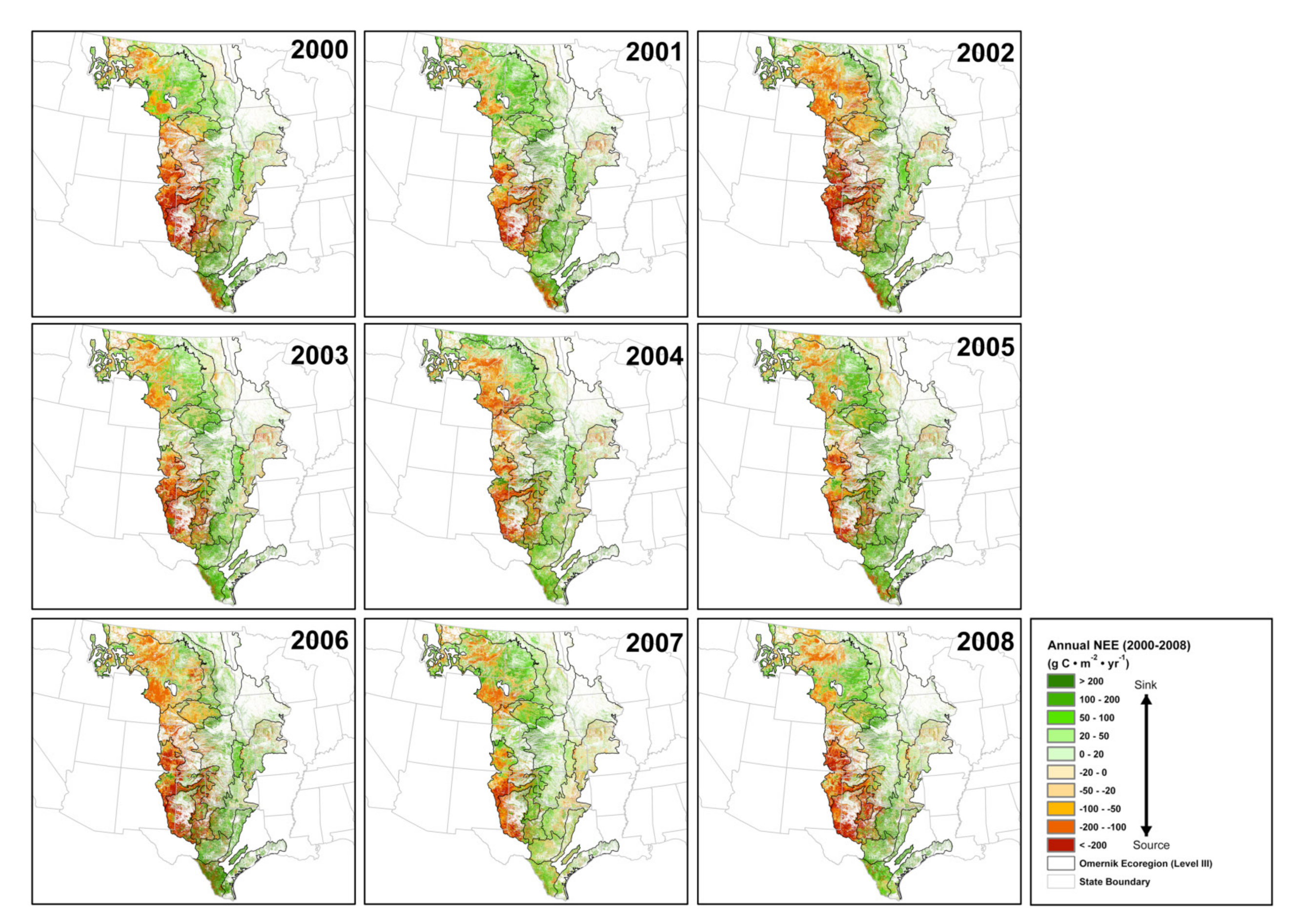

Figure 5. Maps of annual NEE in the Great Plains grasslands during 2000–2008.

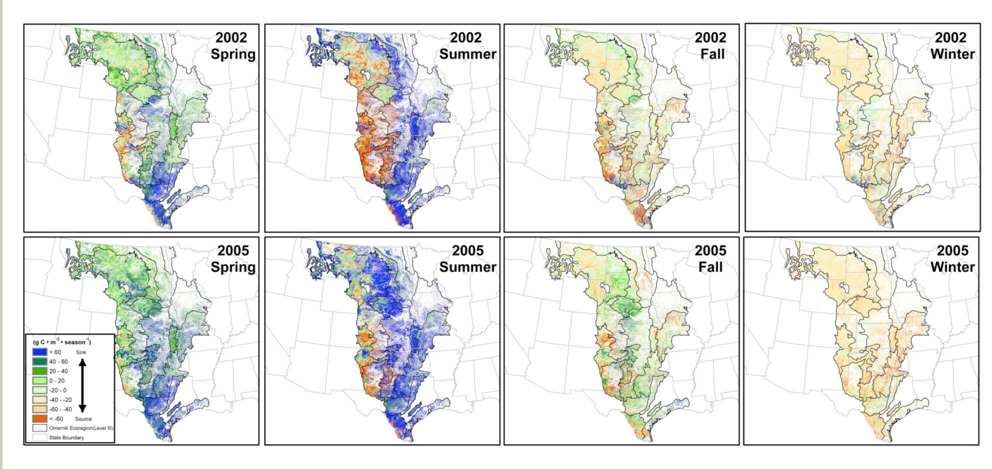

Figure 6. The spatial distribution of PWR-estimated NEE in 2002 and 2005 for spring (March–May), summer (June–August), fall (September–November), and winter (December–February).

3.3 Carbon Sink and Source by Ecoregion

The spatial and temporal patterns of NEE in each ecoregion of the Great Plains are different (Figure 8). The Western High Plains and Southwestern Tablelands were always carbon sources. The Northwestern Great Plains was carbon sources in 2002, 2004, and 2006 with an average annual NEE of –1 $g\ C \cdot m^{-2} \cdot yr^{-1}$ during 2000-2008. The Western Gulf Coastal Plain and the Edwards Plateau had the largest carbon sinks with an average of 144 $g\ C \cdot m^{-2} \cdot yr^{-1}$ and 129 $g\ C \cdot m^{-2} \cdot yr^{-1}$, respectively.

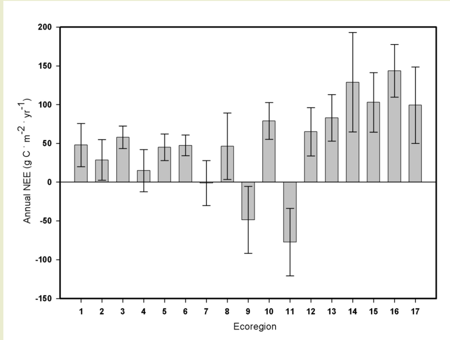

Figure 8. Average annual NEE from 2000 to 2008 for 17 Omernik ecoregions. (Error bar: standard deviation of 9-year estimated annual NEE). In the X-Axis, the numbers represent 17 ecoregions defined similar to the numbers in Figure 1.

4. Conclusions

1. The Great Plains grassland was a sink for carbon with the total of 2,996 T g C during 2000–2008. The year 2005 had the highest rate of net annual CO2 uptake (47.7 $g\ C \cdot m^{-2} \cdot yr^{-1}$) and the year 2002 had the lowest values of annual CO_2 uptake (0.3 $g\ C \cdot m^{-2} \cdot yr^{-1}$).

2. Comparing 2002 (smallest sink year) and 2005 (largest sink year), most of the areas in 2005 were carbon sinks with about 100 $g\ C \cdot m^{-2} \cdot yr^{-1}$ and most of the areas in 2002 were carbon sources with about –150 $g\ C \cdot m^{-2} \cdot yr^{-1}$.

3. The Western High Plains and Southwestern Tablelands were always carbon sources during the 9 years. The Northwestern Great Plains was carbon sources in 2002, 2004, and 2006. The Western Gulf Coastal Plain and the Edwards Plateau were the largest carbon sinks during the study period.

5. Acknowledgements

Funding provided by the USGS Geographic Analysis and Monitoring Program and the Geologic Division. We are grateful for the flux tower data provided by selected AmeriFlux network, USDA Agriflux network, and other flux tower investigators.

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U.S. Department of the Interior
U.S. Geological Survey

April 2010